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Voltage stability by reactive power rescheduling using PSO Algorithm

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Abstract

Voltage stability is a major issue in a power system and in this paper, generator reactive power rescheduling is used for voltage stability enhancement without additional installation cost. Due to system disturbances the active power as well as reactive power flows changes. Generators being always connected to the system reactive power rescheduling of generators can be effectively done. The optimum values of rescheduling is found using Particle Swarm Optimization (PSO) algorithm. The procedure is simulated with an objective of minimizing total reactive power lost in the system with constraints of load balance, bus voltages with suitable limits, and real and reactive power outputs of generators within the maximum and minimum load. The simulations are done using MATLAB.

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Keywords: Voltage stability; Reactive power losses; Reactive power reschedule; Particle Swarm Optimization(PSO).

1. Introduction

Operation analysis of any electric power system shows that frequency and voltage are the main indicators of proper system operation. Disturbance in the system operation causes variation in these two parameters separately or jointly. In case of severe disturbances, the frequency or voltage variations may be abnormally high indicating the system instability. Frequency variation is caused by the real power mismatch, while voltage is the indicator of the reactive power mismatch [1,2,3].

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For the system reliability, both P(active power) and Q (reactive power) consumptions must be controlled properly. As there is a direct link between voltage and the reactive power consumed, control of voltage within the limits by the control of the reactive power are possible [3]. During normal operation state, the reactive power balance is in such a way that the voltages are within the accepted limits. If there is no difference between reactive power generation and consumption levels, then the voltage will be maintained within the prescribed limits. If there is a mismatch between reactive power generation and consumption in the system, it will result in an inappropriate voltage profile [4.] Reactive power generation and consumption locations have to be very close to each other to avoid excessive reactive power transmission. It is due to this fact that reactive power transmission is a highly localized service. The various voltage control methods which are commonly used are under load tap changers, load shedding and installation of new generating units, synchronous condensers, FACTS devices, capacitor banks and reactive power rescheduling [1.]

Voltage instability and power system security are to be analyzed at various steps from planning stage to real-time implementation process. T. Van Cutsem in[5], classifies the methods which can be used for analysis, in four categories: contingency analysis, load ability limit determination[6, 7, 8], determination of security limits, and preventive and corrective control.

Contingency analysis finds the system response on a particular operating point to credible contingencies that may cause or lead to voltage instability or even ultimately gives way to voltage collapse. The system should be operated in such a way that it is enabled to survive the credible contingencies by providing proper pre- and post-contingency controls[9, 10, and 11]. These can be accomplished by a) static methods based on load flow, modified load flow, multi-time scale simulation, and b) time-domain methods. In this paper contingency analysis is carried along with optimization technique to keep the voltage stable.

Generator's reactive power can be used to control voltage level of the system. The amount of reactive power injection keeps the voltage stable. It also depends on the capacity of the generator. Keeping in mind the above mentioned two facts, optimization techniques will give the best results. Among the different optimization techniques, evolutionary computation techniques give rapid solutions [12]. These optimization algorithms are widely used due to their high precision when applied for engineering problems and simple programming. In Differential Evolution individuals are randomly extracted from the solution population and geometrically manipulated. Particle Swarm Optimization is an effective tool for analysis as it gives better results with few parameters to adjust[12]

Nomenclature

Nb	Number of branches	Pg	Total active power generation
Qlossi	Reactive power losses in *i* th branch	Pgmin	Minimum active power generation
Pd	Total active power demand	Qgmin	Minimum reactive power generation
Ploss	Active power loss	Pgmax	Maximum active power generation
Qd	Total reactive power demand	Qgmax	Maximum active power generation
Vimax	Maximum voltage at the *i* th bus	Vi	Current voltage at the *i* th bus
Qgmin	Minimum reactive power	Vimin	Minimum voltage at the i th bus
Qg	Total reactive power generation	V(k)	Velocity at *k* th iteration
X(k)	Position at *k* th iteration	γ_{1i}, γ_{2i}	constants

2. Reactive power rescheduling

The generators are the primary and main source of reactive power. Generator supplied reactive power is especially an effective resource due to 1) its superior performance at low voltage in comparison to static reactive devices, 2) fast response of excitation system to changes, and 3) having a wide reactive power supply range. Therefore we can select reactive power rescheduling from the generator side which provides an effective way to the control of voltage at the load buses[1].

3. Problem Formulation

The reactive power losses reduce the amount of reactive power availability in the circuit. By optimizing the reactive powers reschedule, the condition with minimum reactive power loss and the voltage remaining in stable range during contingencies. Therefore the problem is formulated as given in equations (3.1) to (3.6).

$$\text{Minimize } f_x = \sum_{i=1}^{N_b} Q_{loss} \tag{3.1}$$

Subjected to power flow constraints

$$P_g - P_d - P_{loss} = 0 \tag{3.2}$$

$$Q_g - Q_d - Q_{loss} = 0 \tag{3.3}$$

And active and reactive power and voltage constraints, For all generators

$$P_{gmin} \le P_g \le P_{gmax} \tag{3.4}$$

$$Q_{gmin} \le Q_g \le Q_{gmax} \tag{3.5}$$

For all the buses

$$V_{ijmin} \le V_{ij} \le V_{ijmax} \tag{3.6}$$

3.1 Particle swarm optimization

For solving engineering optimization problems particle swarm optimization is used as a tool as it is a population based algorithm . This procedure is based on the behavior of flocking birds. The birds in a swarm fly towards the position of food in a random manner. In a similar way the candidate solutions called particles(members of the population) relocate their position with time and update themselves in each iteration to find the solution of the problem from a given solution space. Similar to that process of searching food, the solution to an optimization problem is found out from a solution space [13, 14, 15]. Accuracy along with rate of convergence of this algorithm depends on the appropriate choice of 1) particle size, 2) maximum velocity of particles and 3) discrete time index.

3.2 Algorithm for minimization of reactive power losses

The formulated problem is optimized using Particle Swarm Algorithm(PSO) algorithm. The step involved in this procedure is given below. The flow chart is shown in Fig.1.

Step 1: Parameters are loaded as the input specifying their limits. Here the bus data, line data system data and generator data are the inputs. Initialize the population with a set of random solution.

Step 2: Using Newton-Raphson power flow algorithm line flows and transmission losses are calculated.

Step 3: Objective function parameter (reactive loss) value is calculated for each particle. Compare this value with that of the best solution in the population (PBest). The best solution obtained from the set of PBest is taken as the best solution among all the particles in the population (GBest).The PBest and GBest values are then updated.

Step 4:The velocity and position of each particle is updated using equations 3.7 and 3.8. If any of the particle is outside the limit, its position is set within the proper limits

$$V_i\,(k+1) = V_i(k) + \gamma_{1i}\big(p_i - X_i(k)\big) + \gamma_{2i}\big(G - X_{i(k)}\big) \tag{3.7}$$

$$X_i(k+1) = X_i(k) \;\; + V_i\,(k) \tag{3.8}$$

Step 5: If any one of the following stopping criteria

- If the number of iterations after the last change of the solution is greater than a pre specified number.
- If he number of iterations reaches the maximum allowable number. is satisfied, then go to step 6. Otherwise repeat the steps 2,3 and 4.

Step 6: The particle that produces the latest GBest is the optimal value.

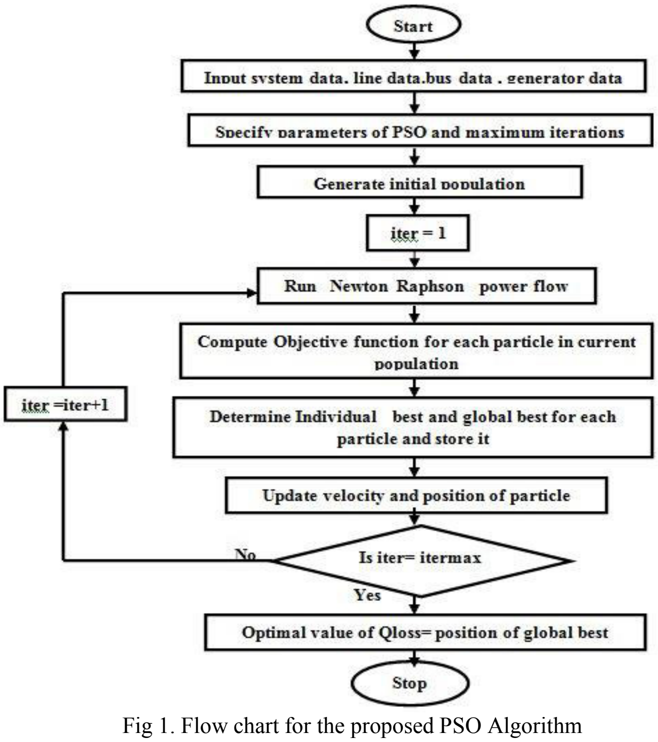

Fig 1. Flow chart for the proposed PSO Algorithm

Table 1: Parameters of PSO

Parameter	***Value***
Particles	50
Iterations	50
Acceleration constant for initial stages	2
Acceleration constant For final stages	2
Initial inertia weight	0.4
Final inertia weight	0.9

4. Simulation

The proposed Particle Swarm Algorithm (PSO) was tested on IEEE 14 bus system. It is a 14 bus system having 5 generators,4 transformers, 14 buses, 16 lines, and 11 loads as shown in Fig 2[16].The generators in the system are located at buses 2, 3, 6 and 8 and 10 and transformers with off-nominal tap ratio are connected in lines 4-7, 5- 6 , 4-9and 8-9. The lower voltage magnitude limit at all buses are 0.9 p.u. and the upper limit is 1.1 p.u.

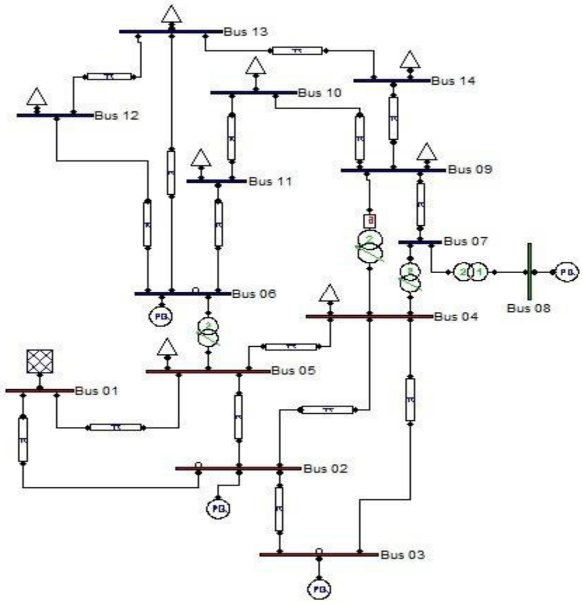

Fig 2. PSAT simulink model of the IEEE 14 bus system

Fig 3. Shows the voltage magnitude profile after power flow analysis during normal conditions. From the figure it is evident that the voltages in the buses is within permissible limits.(ie between 0.9 p.u and 1.1 p.u).

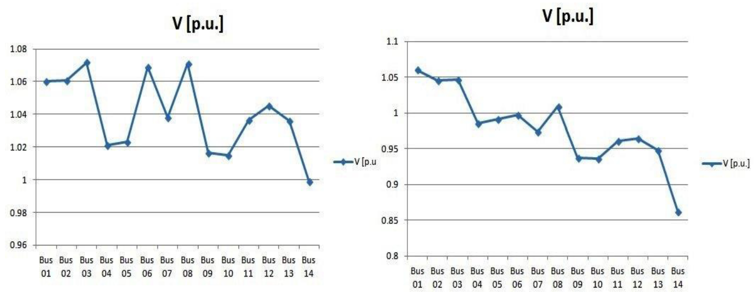

Fig 3 a) Voltage profile during normal condition b)Voltage profile during contingency (overload)

Contingency analysis was done by creating an overloaded condition and line outage condition.

a) Contingency of overloaded condition

A contingency over loaded condition (Increase in reactive load such as starting of induction motor or arc furnace) was simulated. The Newton Raphson power flow analysis was again conducted and it was found that the voltage at bus no.14 has reduced below 0.9 p.u. (0.86216 p.u). From the power flow results we can see that the losses have increased. The PSO algorithm is used to find the optimum value of Qloss as well as the value of needed reactive power generations in the generators to keep the voltage stable. The convergence of Qloss after optimization of the objective function is shown in Fig 4. Starting from random values it reaches a minimum point which gives the optimal value. Comparison of the voltages during normal condition, contingency condition and voltage after power flow using the values of reactive power to be injected to the generator buses from the optimization results are shown in Fig.5a). It indicates that with the optimization technique the voltage has improved during contingency.

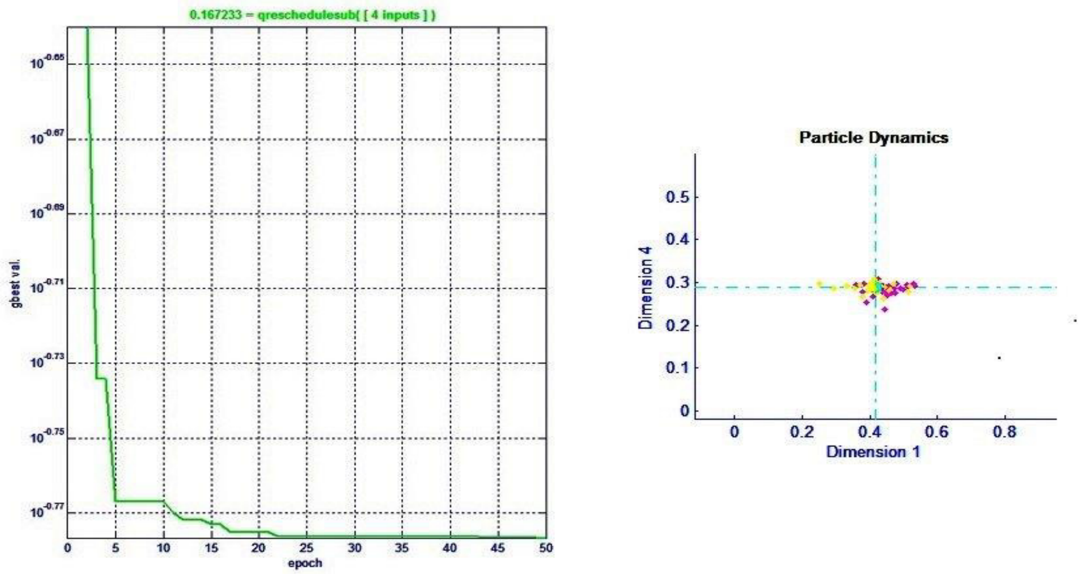

Fig 4. a) Convergence property of proposed algorithm for overloaded condition b)Particle dynamics

This is achieved by rescheduling generator reactive power with the help of Particle swarm optimization algorithm. The reactive power at generators 2,3,6,8 are set to the value of reactive power obtained after optimization. The power flow results indicate that the voltage has improved.

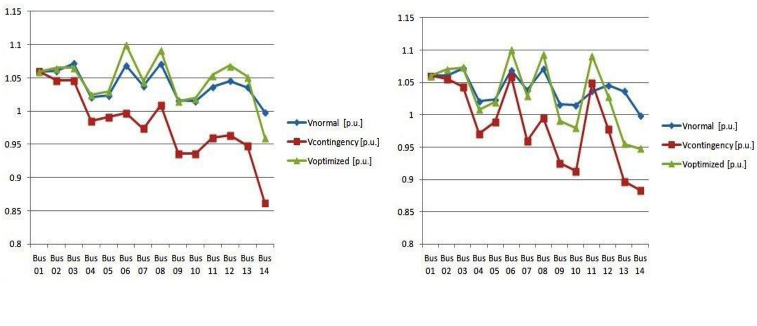

Fig 5. a) Voltages during Overloaded condition b) Voltages during Fault condition

The value of reactive losses during contingency has increased to 0.25509 p.u and after optimization it has reduced to

0.16723 p.u. Thus our objective of voltage stability along with reactive loss reduction is achieved. Figure 6.(a) shows the voltage profile after optimization.

b) *Contingency condition of line outage*

The contingency of line outage which is a common contingency condition was simulated. The voltage during contingency condition was found to be less than 0.9 p.u. Fig 6 b) shows the voltage profile during contingency The Fig 5b) shows the comparison of voltages during normal , fault condition and after optimization. During contingency the voltage has reduced below 0.9p.u in buses 13 and 14. After optimization the voltage levels increased above 0.9 p.u.

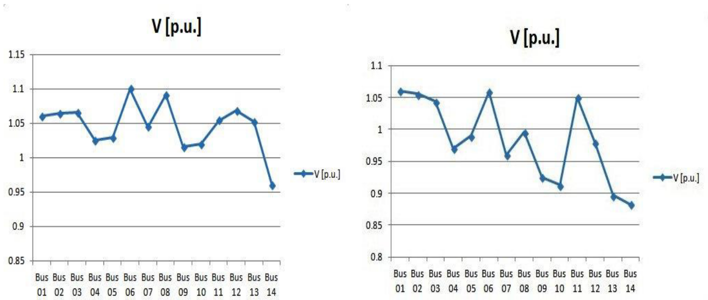

Fig.6 a) Voltage profile after Optimization (Overloaded) b) Voltage profile during Contingency (Fault)

In this case also the PSO algorithm is used to find the optimum value of Qloss as well as the value of needed reactive power generations in the generators. The convergence of Qloss after optimization is shown in Fig 7a) . Starting from random values it reaches a minimum point which gives the optimal value. The particle dynamics is shown in Fig 7b).

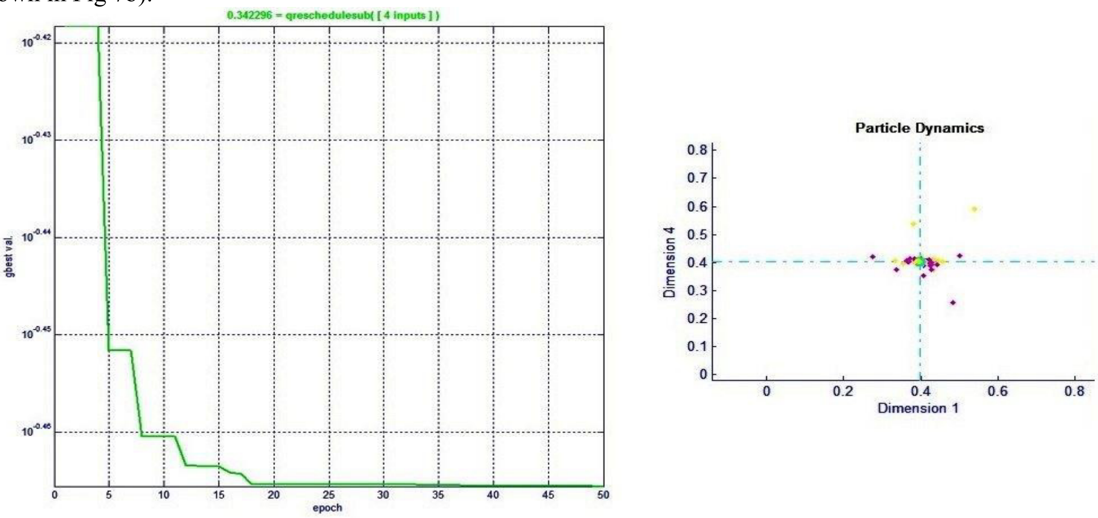

Fig 7 a) Convergence property of proposed algorithm for line outage b) Particle dynamics

5. Result Analysis

The outcomes of the analysis is tabulated in Table 2 the reactive power losses during contingency1 (overloaded condition) is 25.509 MVAR. The loss after optimization has decreased to 16.723 MVAR. Percentage reduction in losses is about 34.44%.

The reactive power losses during contingency 2(fault condition) is 38.664 MVAR. The losses after optimization have decreased to 34.238 MVAR. Percentage reduction in losses is about 11.45%. This will give a cost reduction if it is accounted in terms of economic considerations.

Table.2 Result Analysis of overloaded condition and fault condition

	Overloaded condition(Contingency 1) (p.u)				Fault condition (Contingency 2) (p.u)			
Condition	Voltage at bus no 14	Reactive power at generator 2,3,4,8	Reactive losses	Active losses	Voltage at bus no 13 and14	Reactive power at generator 2,3,4,8	Reactive losses	Active losses
Normal	0.99868	0.3000 0.3000 0.2000 0.2000	0.12518	0.09046	1.03606 0.99868	0.3000 0.3000 0.2000 0.2000	0.12518	0.09046
Contingency	0.86216	0.3000 0.3000 0.2000 0.2000	0.25509	0.11696	0.89676 0.88292	0.3000 0.3000 0.2000 0.2000	0.38664	0.15679
After Optimization	0.95996	0.4154 0.1783 0.5412 0.2907	0.16723	0.10738	0.95525 0.94757	0.3912 0.3403 0.2135 0.4013	0.34238	0.14436

6. Conclusion

Reactive power rescheduling was applied in this paper and it was found that by using the particle swarm optimization technique the reactive losses can be reduced along with the voltage stability achievement. The optimal placement of generators for economic operation is possible by using this technique. The use of this technique provides an added advantage of reduction of active power losses.

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